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Elevated indoor air pollution levels due to the burning of biomass in developing countries are well established. Few studies have quantitatively assessed air pollution levels of improved cookstoves and examined these measures in relation to health effects. We conducted a cross-sectional survey among 79 Honduran women cooking with traditional or improved cookstoves. Carbon monoxide and fine particulate matter ($PM_{2.5}$) levels were assessed via indoor and personal monitoring. Pulmonary function and respiratory symptoms were ascertained. Finger-stick blood spot samples were collected to measure C-reactive protein (CRP) concentrations. The use of improved stoves was associated with 63% lower levels of personal $PM_{2.5}$, 73% lower levels of indoor $PM_{2.5}$, and 87% lower levels of indoor carbon monoxide as compared to traditional stoves. Women using traditional stoves reported symptoms more frequently than those using improved stoves. There was no evidence of associations between cookstove type or air quality measures with lung function or CRP.

Keywords: indoor air pollution; particulate matter; pulmonary function; respiratory symptoms; C-reactive protein

Introduction

More than half of the world's population relies on biomass combustion to meet basic domestic energy needs (Smith et al. 2004). Cooking in many developing countries usually consists of burning solid fuels over open fires or using traditional stoves that usually emit high levels of pollutants. Improved stoves have been designed to burn fuel more efficiently and have usually incorporated a chimney or flue for ventilation and have the potential to substantially reduce indoor air pollution exposures (Naeher et al. 2000; Ezzati and Kammen 2002; Smith 2002; Bruce et al. 2004). However, evaluations of improved stoves are limited (Smith 2002). Biomass-derived indoor air pollution in developing countries has been associated with increased risks of respiratory diseases (Bruce et al. 2000; Ezzati and Kammen 2002; Smith 2002; Schei et al. 2004; Smith et al. 2004; Naeher et al. 2005). Most studies have relied on

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proxies of exposure, such as type of stove (traditional or improved) or fuel and often lacked adjustment for potential confounders (Bruce et al. 1998; Smith 2002). Research on the association between cookstove exposures and cardiovascular disease is limited. Assessing biomarkers of inflammation such as those commonly assessed in the ambient air pollution literature (e.g. C-reactive protein [CRP]) (Seaton et al. 1999; Peters et al. 2001; Ruckerl et al. 2006), may help elucidate this relationship; however, studies may be limited by difficulty in collecting and handling blood samples in settings typical of developing countries. Collecting dried blood spots via finger-stick may provide a useful tool for examining this relationship (Parker and Cubitt 1999; Mei et al. 2001; McDade et al. 2004).

We conducted a cross-sectional investigation to evaluate quantitative air pollution levels and health effects, including symptoms and pulmonary function, associated with traditional and improved *Justa* stoves in Honduras. In addition, we measured CRP, a biomarker of inflammation and risk factor for cardiovascular disease (Ridker 2001), in dried blood spots. This pilot study was conducted in part to identify methodological issues and difficulties associated with cookstove exposure and health effects research that may influence longitudinal and intervention studies in developing country settings.

Methods

The data collection period was from June through August 2005. Fifty-nine non-smoking women who used cookstoves in enclosed or semi-enclosed kitchens participated from two Honduran communities: 30 from Santa Lucia and 29 from Suyapa. An additional 20 women from Santa Lucia participated in an abbreviated study protocol that did not include the quantitative air quality measurements. Approximately half of the women cooked using traditional stoves ($n = 38$) and half using improved stoves ($n = 41$). Traditional stoves typically consisted of open fire or poorly designed combustion chambers and some included poorly functioning chimneys. The improved *Justa* stoves incorporated a chimney and an improved combustion chamber. All participants gave informed consent and the study was approved by the Institutional Review Board of Colorado State University (CSU).

Exposure monitoring began around 8 am each morning and lasted for approximately eight hours. $PM_{2.5}$ (particulate matter with an aerodynamic diameter of less than or equal to 2.5 μm) was assessed via 8-hour indoor and outdoor monitoring and 8-hour personal monitoring using PEM samplers (SKC Inc., PA) and 37 mm Teflon polytetraflouroethylene filters (2 μm pore size). Filters were pre- and post-weighed using a Mettler MT5 balance (Mettler-Toledo International, Inc.). Carbon monoxide was assessed via 8-hour indoor monitoring and 20-min outdoor monitoring using a direct reading instrument (Q-TRAK Plus IAQ Monitor; TSI Inc., MN, USA). The Q-TRAK was pre- and post-calibrated using zero air and 35 ppm carbon monoxide gas cylinders (TSI Inc., MN). $PM_{2.5}$ and carbon monoxide indoor sampling devices were collocated inside the kitchen at a height representative of breathing zones. Personal $PM_{2.5}$ was assessed by attaching the sampler to the participant's clothing nearest her breathing zone and placing the pump (Universal, SKC Inc., PA, USA) in a pack worn around her waist. Investigators assessed kitchen volume, building materials, size of eave spaces and windows, and temperature.

Health endpoints were assessed at the end of the exposure monitoring period for each participant. Forced expiratory volume in one second (FEV_1) and peak expiratory flow (PEF) were measured using the portable PiKo-1 peak flow meter (Pulmonary Data Services, Inc., CO, USA) (Fonseca et al. 2005). CRP concentration was measured in dried blood spot samples. A finger-stick blood sample was collected from each participating woman. The puncture site was cleansed with 70% isopropanol. Participants' fingers were pricked with a sterile, disposable Tenderlett (ITC, NJ, USA) lancet with a 1.75 mm point. Drops of blood were spotted onto standardized filter paper (903 Protein Saver Card, Schleicher & Schuell, NH, USA). Blood spots were dried overnight at room temperature in a horizontal position and then stored in low gas-permeable zip-closure bags with desiccant packets and humidity indicator cards (Hannon et al. 1997). Samples were frozen in Honduras and transported to CSU where they were stored at $-80^{\circ}C$.

The high-sensitivity CRP dried blood spot assay was modified from that of McDade et al. (2004) by utilizing a commercially available enzyme-linked immunosorbent assay (ELISA) kit (Virgo CRP Kit, Hemagen Diagnostics, Inc, Columbia MD, USA). The modification, which was performed due to cost constraints and reagent availability at the time, included using a microplate with pre-coated anti-CRP in each well; all other procedures remained the same as in McDade et al. (2004). We performed a small validation study of the modified dried blood spot CRP assay comparing CRP in plasma and dried blood spots from 40 volunteers. In the validation study, dried blood CRP was consistently higher than plasma CRP measured in the same person (regression equation: dried blood CRP $= 5.91$ [plasma CRP] $+ 1.53$; $R^2 = 0.75$).

A standardized respiratory symptoms and disease questionnaire developed and validated by the American Thoracic Society (Ferris 1978) was translated into Spanish and administered to participants. Additionally, a study investigator measured each participant's height, weight, and waist circumference. The survey also collected demographic information, occupation, and information related to exposure (e.g. fuel type and time spent cooking) (Albalak et al. 2001) and outcome (e.g. medication and supplement use and recent illnesses).

All analyses were performed using the SAS statistical software (SAS 9.1, SAS Institute, Inc., Cary, NC, USA). Multiple linear regression was used to assess the relationship between cookstove type and air quality measures with lung function or CRP concentrations. To meet assumptions of linear regression, the natural logarithm transformation of CRP concentration was used. Multiple logistic regression was used to assess the relationship between cookstove exposures and air quality measures with symptoms. Cookstove exposures were assessed in separate models (personal 8-hour average $PM_{2.5}$, indoor 8-hour average $PM_{2.5}$, indoor 1-hour maximum carbon monoxide, and stove type [traditional or improved]). All estimates and confidence intervals for $PM_{2.5}$ and carbon monoxide concentrations were expressed for an interquartile range (IQR) increase of the pollutant. Models included age (symptoms analyses); age and height (lung function analyses); and age, height, and waist circumference (CRP analyses). We also evaluated second-hand smoke exposure, education level, outdoor afternoon average temperature, and, in the CRP analyses only, fish consumption, menopausal status, and the presence of a cold or sinus problem in the previous week as potential confounders.

Models were stratified by several variables in order to evaluate the heterogeneity of the estimates, including second-hand smoke exposure, outdoor concentrations of $PM_{2.5}$, village of residence, amount of time spent in the room with the fire burning, outside average afternoon temperature, reported concern that stove smoke causes health problems, years with the current stove, ventilation factors (in models with stove type; e.g. presence of kitchen windows, volume of kitchen), presence of a cold or sinus problem during the previous week (CRP analyses), history of smoking, and bronchodilator use (lung function models only).

A secondary analysis was performed in order to assess the relationship between cookstove type and air quality measures and percent predicted FEV_1 (less than 80% vs. 80% or more) using logistic regression. Because standardized reference equations for Honduran women do not exist (to our knowledge), predicted FEV_1 for each participant was based on age and height-adjusted reference equations for Mexican-American women (Hankinson et al. 1999).

Results

The use of improved *Justa* stoves was associated with 63% lower levels of personal $PM_{2.5}$, 73% lower levels of indoor $PM_{2.5}$, and 87% lower levels of indoor carbon monoxide levels compared to traditional stoves (Table 1). Only four women (5.1%) reported being previous cigarette smokers (all women reported being non-smokers at the time of the study); however, 31.7% reported the presence of smokers in the house

Table 1. Population characteristics, air quality, and health endpoints among traditional and improved stove users ($n = 79$).

	Traditional stove users ($n = 38$)	Improved stove users ($n = 41$)
Population characteristics: Mean (standard deviation [SD])		
Age (years)	37.8 (15.7)	45.0 (13.0)
Body Mass Index (kg/m^2)	25.6 (3.5)	26.9 (5.2)
Height (meters)	1.52 (0.07)	1.50 (0.05)
Waist circumference (cm)	91.2 (9.1)	92.2 (13.5)
Education (years)	3.9 (2.8)	3.9 (2.6)
Years with current stove	9.0 (9.2)	2.4 (1.4)
Population characteristics: Frequency (percent)		
Second-hand smoke exposure	10 (26.3)	15 (36.6)
Air quality:* Mean (SD)		
$PM_{2.5}$, personal (μg/m^3; 8-hour average)	197.7 (135.5)	73.6 (34.0)
$PM_{2.5}$, indoor (μg/m^3; 8-hour average)	1002.3 (1089.4)	266.3 (240.2)
Carbon monoxide, indoor 1-hour max. (ppm)	14.3 (13.1)	1.8 (3.2)
Self-reported symptoms: Frequency (percent)		
Cough	11 (29.0)	2 (4.9)
Phlegm	7 (18.4)	3 (7.3)
Wheeze	9 (23.7)	0 (0)
Nasal irritation	11 (29.0)	11 (26.8)
Headache	16 (42.1)	5 (12.2)
*Lung function and CRP:** Mean (SD)*		
FEV_1 (l)	2.14 (0.40)	1.93 (0.44)
PEF (l/min)	272.1 (61.8)	249.2 (56.2)
CRP (mg/l)	3.3 (4.8)	5.2 (4.0)

*Traditional stove sample sizes: $n = 28$ for personal $PM_{2.5}$, $n = 27$ for indoor $PM_{2.5}$, $n = 26$ for carbon monoxide; improved stove sample sizes: $n = 30$ for personal $PM_{2.5}$, $n = 30$ for indoor $PM_{2.5}$, $n = 28$ for carbon monoxide. **Lung function sample sizes: $n = 24$ traditional stove and $n = 28$ improved stove users; CRP sample sizes: $n = 35$ traditional stove and $n = 36$ improved stove users; geometric mean presented for CRP. FEV_1, forced expiratory volume in 1 sec; PEF, peak expiratory flow; CRP, C-reactive protein.

or kitchen. On average, traditional stove users were about 7 years younger, had their current stove for 6.6 years longer, and were exposed to less second-hand smoke (26.3% vs. 36.6%) compared to improved stove users; body mass index, height, waist circumference, and years of education were similar among the two groups (Table 1).

Adjusting for age and height, an IQR increase (106.1 $\mu g/m^3$) of personal $PM_{2.5}$ was associated with a 0.07 liter (95% confidence interval (CI): 0.01–0.13) increase in FEV_1 (Table 2). Associations of indoor $PM_{2.5}$, carbon monoxide, and stove type (improved vs. traditional) with FEV_1 (adjusted for age and height) were consistent with null associations (Table 2). Associations of cookstove type and air quality measures with PEF were similar to those for FEV_1 (Table 2). Associations of cookstove type and air quality measures with log-transformed CRP concentrations (adjusted for age, height, and waist circumference) were consistent with null associations (Table 3). Geometric mean CRP concentrations (adjusted for age, height, and waist circumference) for traditional and improved cookstove users were 3.7 mg/l (95% CI: 2.3–5.8) and 4.7 mg/l (95% CI: 3.0–7.3), respectively.

Odds ratios (OR) for the associations of cookstove type and air quality measures with symptoms (adjusted for age) are presented in Table 4. Cooking with a traditional stove was associated with the usual presence of a cough (OR = 7.99, 95% CI: 1.59–40.09), phlegm (OR = 3.83, 95% CI: 0.86–17.14), headache during cooking (OR = 5.59, 95% CI: 1.73–18.06), and shortness of breath (OR = 2.33, 95% CI: 0.83–6.57); the confidence intervals were wide and some did not exclude a null association. We did not observe evidence of an association between cookstove type and nasal irritation (OR = 0.92, 95% CI: 0.33–2.60). Associations of indoor $PM_{2.5}$ and carbon monoxide levels with symptoms, while weak, generally supported the results for stove type (Table 4). Associations between personal $PM_{2.5}$ and symptoms were consistent with null associations (Table 4).

Adjustment for additional variables (second-hand smoke exposure, education level, outdoor afternoon average temperature) did not substantially alter the results. Results from stratified models, including reported exposure to second-hand smoke, did not provide evidence of heterogeneity across the strata.

Table 2. Multiple linear regression estimates and 95% confidence intervals (CI) for the association of air quality measures and cookstove type with forced expiratory volume in 1 second (FEV_1; liters) and peak expiratory flow (PEF; liters/minute); associations adjusted for age and height.

Exposure measure*	*n*	FEV_1 Coefficient (liters)	95% CI
8-hour average personal $PM_{2.5}$ ($\mu g/m^3$)	44	0.07	0.01 to 0.13
8-hour average indoor $PM_{2.5}$ ($\mu g/m^3$)	43	−0.0002	−0.07 to 0.07
1-hour maximum carbon monoxide (ppm)	40	0.02	−0.05 to 0.10
Stove type (traditional vs. improved)	52	0.05	−0.11 to 0.20
Exposure measure*	N	PEF Coefficient (l/min)	95% CI
8-hour average personal $PM_{2.5}$ ($\mu g/m^3$)	44	16.0	2.7 to 29.3
8-hour average indoor $PM_{2.5}$ ($\mu g/m^3$)	43	−4.8	−20.1 to 10.5
1-hour maximum carbon monoxide (ppm)	40	−4.4	−23.5 to 14.8
Stove type (traditional vs. improved)	52	12.7	−19.9 to 45.4

*Estimates for $PM_{2.5}$ and carbon monoxide are per IQR increase: personal $PM_{2.5}$ (106.1 $\mu g/m^3$), indoor $PM_{2.5}$ (572.3 $\mu g/m^3$), and indoor carbon monoxide (4.62 ppm). $PM_{2.5}$, particulate matter with an aerodynamic diameter of less than or equal to 2.5 μm.

Table 3. Multiple linear regression estimates and 95% confidence intervals (CI) for the association of air quality measures and cookstove type with natural log transformed C-reactive protein concentrations (CRP; mg/l); associations adjusted for age, height, and waist circumference.

Exposure measure*	*n*	Coefficient	95% CI
8-hour average personal $PM_{2.5}$ ($\mu g/m^3$)	50	−0.2	−0.5 to 0.01
8-hour average indoor $PM_{2.5}$ ($\mu g/m^3$)	49	0.0003	−0.2 to 0.2
1-hour maximum carbon monoxide (ppm)	47	0.1	−0.2 to 0.3
Stove type (traditional vs. improved)	71	−0.2	−0.9 to 0.4

*Estimates for $PM_{2.5}$ and carbon monoxide are per IQR increase: personal $PM_{2.5}$ (106.1 $\mu g/m^3$), indoor $PM_{2.5}$ (572.3 $\mu g/m^3$), and indoor carbon monoxide (4.62 ppm). $PM_{2.5}$, particulate matter with an aerodynamic diameter of less than or equal to 2.5 μm.

Discussion

In this study of Honduran women, the use of improved *Justa* stoves was associated with 63% lower levels of personal $PM_{2.5}$, 73% lower levels of indoor $PM_{2.5}$, and 87% lower levels of indoor carbon monoxide levels compared to traditional stoves. Women using traditional stoves reported symptoms of cough, phlegm, wheeze, headache during cooking, and shortness of breath more frequently than those using improved stoves; results for indoor $PM_{2.5}$ and carbon monoxide levels, while weak, generally supported the results for stove type. The results of this pilot study provide evidence of the potential impact on exposure and health of the improved *Justa* stove in this population. The results also demonstrate the need for continued evaluation of improved wood-burning stoves in order to justify costly intervention programs in developing countries. Additionally, this study, in conjunction with recent advances in laboratory methods, illustrates the feasibility of using dried blood spot collection in a developing country in order to evaluate biologic markers in environments with limited resources.

In this study, we observed associations between stove type and self-reported symptoms which were supported by weaker associations between measured indoor air pollutants and self-reported symptoms. Previous studies have demonstrated that women exposed to higher levels of indoor air pollution from the burning of biomass fuels are more likely to experience adverse symptoms (Smith et al. 2004; Regalado et al. 2006), although not consistently (Riojas-Rodriguez et al. 2001). Inconsistent evidence of the relationship between cookstove exposures and reported symptoms may arise because of discrepancies in the understanding of terms used to describe symptoms, particularly because rural areas of developing countries are often characterized by low literacy and poor access to health care (Diaz et al. 2007; Thompson et al. 2007). Another potential limitation of the symptoms analyses is the potential of reporting bias; that is, the knowledge of the adverse health effects of cookstoves could have influenced women with traditional stoves to report more symptoms because of this knowledge. In this study, most women (76%) reported that they were concerned that the smoke from cookstoves could adversely affect their health. Ideally, we would have examined the association between exposure and health among women not expressing concern; however, due to limited sample size we were unable to examine associations among these 19 women (24%).

Our results examining cookstove type and measured air pollution do not support the hypothesis that improved stoves result in better lung function. In similar studies,

Table 4. Age-adjusted odds ratios (OR) and 95% confidence intervals (CI) for the associations of air quality measures and cookstove type with self-reported symptoms.

	n	Cough OR (95% CI)	Phlegm OR (95% CI)	Wheeze OR (95% CI)	Nasal irritation OR (95% CI)	Headache during cooking OR (95% CI)	Shortness of breath OR (95% CI)
8-hour average personal $PM_{2.5}$ ($\mu g/m^3$)	58	1.05 (0.54, 2.06)	0.81 (0.32, 2.05)	0.94 (0.45, 1.97)	0.70 (0.34, 1.44)	1.19 (0.72, 1.95)	0.94 (0.58, 1.54)
8-hour average indoor $PM_{2.5}$ ($\mu g/m^3$)	57	1.49 (0.84, 2.68)*	1.26 (0.74, 2.15)	1.64 (1.02, 2.62)	0.60 (0.30, 1.16)	1.26 (0.85, 1.86)	1.33 (0.85, 2.08)
1-hour max indoor carbon monoxide (ppm)	54	1.33 (0.58, 3.05)*	1.08 (0.49, 2.39)	1.42 (0.76, 2.63)	0.52 (0.23, 1.22)	1.45 (0.84, 2.52)	2.05 (0.95, 4.42)
Stove type (traditional vs. improved)	79	7.99 (1.59, 40.09)	3.83 (0.86, 17.14)	NA**	0.92 (0.33, 2.60)	5.59 (1.73, 18.06)	2.33 (0.83, 6.57)

*Adjusted for age and reported exposure to second-hand smoke; **24% of the women using traditional stoves reported wheeze while 0% of the women cooking with improved stoves reported the symptom. Estimates for $PM_{2.5}$ and carbon monoxide are per IQR increase: personal $PM_{2.5}$ (106.1 $\mu g/m^3$), indoor $PM_{2.5}$ (572.3 $\mu g/m^3$), and indoor carbon monoxide (4.62 ppm). CI, confidence interval; OR, odds ratio; $PM_{2.5}$, particulate matter with an aerodynamic diameter of less than or equal to 2.5 μm.

associations between biomass exposures and lung function have been weak and variable (Reddy et al. 2004; Regalado et al. 2006; Rinne et al. 2006; Diaz et al. 2007). Explanations for the lack of consistent associations despite elevated exposures are unknown (Regalado et al. 2006). It is possible that biomass smoke has no or little impact on lung function or that women chronically exposed to biomass smoke have developed reduced susceptibility (Regalado et al. 2006). Furthermore, the most susceptible time frame may be during childhood when all of the women likely experienced similarly high exposures due to the use of traditional stoves as children (USEPA 1992; Rinne et al. 2006). In addition, air pollution levels measured for the improved stove users (mean personal $PM_{2.5} = 73.6\ \mu g/m^3$; mean indoor $PM_{2.5}$ 266.3 $\mu g/m^3$, mean indoor 1-hour maximum carbon monoxide = 1.8 ppm), while lower than the traditional stove users, are still relatively high, which may limit the ability to detect health differences among the women if a threshold exists. The indoor $PM_{2.5}$ levels observed in this study are similar to those observed for other improved biomass stoves, including wood- and dung-burning cookstoves in India (Chengappa et al. 2007; Dutta et al. 2007), wood-burning cookstoves in Mexico (Masera et al. 2007), and wood-burning cookstoves in Guatemala (Naeher et al. 2000; Albalak et al. 2001; McCracken et al. 2007). In addition, Cynthia et al. (2008) suggest that the relationship between reductions in kitchen concentrations and reductions in personal concentrations are not consistent and may differ based on stove type. In this study, personal carbon monoxide concentrations were not assessed which may limit interpretation of results if carbon monoxide is the health-damaging pollutant and if changes in indoor carbon monoxide do not reflect changes in personal carbon monoxide. However, $PM_{2.5}$ was the primary pollutant of interest and personal concentrations of this pollutant were assessed for each participant. Finally, our use of education level as an indicator of socioeconomic status may have resulted in residual confounding. Studies in Guatemala have examined more culturally-appropriate indicators of socio-economic status not available in this study, including an asset index incorporating the possession of a radio, a television, and/or a bicycle, as well as owning pigs or cattle (Bruce et al. 1998; Díaz et al. 2007; McCracken et al. 2007).

Personal $PM_{2.5}$ levels were associated with FEV_1 in the direction opposite to that hypothesized (i.e. increased levels of personal $PM_{2.5}$ were associated with improved lung function). The increases in lung function observed when exposures increased are likely not clinically meaningful. Because changes in FEV_1 are difficult to interpret, values are typically compared to a predicted level within a population. While to our knowledge reference values are not available for Honduran women, in our secondary analyses using Mexican-American reference values for FEV_1, the results did not provide evidence of an association for cookstove type or air pollution measures. Increasing age was associated with decrements in lung function and increasing height was associated with increases in lung function, as would be expected (Hankinson et al. 1999); therefore, some confidence can be placed in the lung function values. The unexpected result for personal $PM_{2.5}$ and FEV_1 may partially be explained by the inability of a cross-sectional study design to determine temporality of exposure and disease. It is possible that women already experiencing the most adverse health effects were the women who received improved stoves. The women in this study were selected to receive the improved stoves by a local non-profit organization, and we do not have any information regarding why women were selected to receive new stoves. Women with improved stoves were on average 7.2 years older than women using traditional stoves. Because improved stoves had been disseminated an average of 2.4 years prior to the study, the total lifetime use of traditional stoves may have actually been longer for the improved stove user group.

In this study, estimates of the associations between cookstove type and air quality measures with CRP were consistent with null associations. Studies have reported associations between ambient air pollution exposures and increased CRP concentrations (Seaton et al. 1999; Peters et al. 2001; Ruckerl et al. 2006), although not consistently (Diez Roux et al. 2006). CRP is an indicator of systemic inflammation, and elevated concentrations have been associated with risk of cardiovascular disease (Ridker 2001). Few studies have assessed the relationship between biomass burning exposures and cardiovascular health in developing countries. The use of improved stoves versus traditional open fires was associated with reductions in systolic and diastolic blood pressure in Guatemala (McCracken et al. 2007). Ray et al. (2006) reported increased activation of platelets and formations of platelet leukocyte complexes among biomass users compared to liquid petroleum gas users in India. In addition, Barregard et al. (2006) reported small exposure-related increases in inflammatory mediators, such as Serum Amyloid A and Factor VIIIc, and a 10% increase in CRP levels three hours after controlled exposure to wood smoke compared to the same amount of time following clean air exposure.

One goal of this study was to measure CRP as an indicator of chronic inflammation due to long-term biomass smoke exposures (Macy et al. 1997; Danesh et al. 2004; McDade 2006); however, it is possible that the CRP concentrations were influenced by acute exposures. Results from our validation study indicated that dried blood CRP was consistently higher than plasma CRP measured in the same person (regression equation: dried blood CRP = 5.91 [plasma CRP] + 1.53; $R^2 = 0.75$). Therefore, dried blood CRP concentrations measured among the Honduran participants (ranging from 0.02 to 41.0 mg/l) were reasonably consistent with plasma CRP concentrations less than 10 mg/l, indicating that these women had not likely experienced acute infection or injury prior to sample collection.

Despite the documented high exposures, estimates concerning the health effects of biomass burning have considerable uncertainty (Zhang and Smith 2003). Few studies have quantitatively assessed personal and indoor air pollution levels related to improved cookstoves and examined these measures in relation to health effects, particularly cardiovascular health effects. Continued evaluations of exposure reductions and health improvements are needed in order to encourage and justify the use and dissemination of improved wood-burning stoves, especially in parts of the world where wood is the preferred or necessary cooking fuel. It is likely that the global burden of disease due to indoor air pollution from biomass burning will be even greater once the cardiovascular disease health impacts are more clearly understood (Smith 2002). Assay methods have now been validated for a large number of markers of systemic inflammation in dried blood spots (Mei et al. 2001; McDade et al. 2004; Skogstrand et al. 2005), including markers that may be better indicators of cardiovascular and pulmonary health than CRP. With further refinement, the minimally invasive use of dried blood spots could provide a viable alternative to venipuncture blood collection; several community-based studies have demonstrated it to be a convenient and reliable means to blood collection, storage, and transportation (Worthman and Stallings 1997; Cook et al. 1998; Erhardt et al. 2002; McDade et al. 2004; McDade et al. 2007). This field method could prove to be a useful tool for evaluating multiple biological markers, including DNA (Steinberg et al. 2002), to further elucidate the relationship between indoor air pollution and cardiovascular and respiratory health effects in developing countries (Parker and Cubitt 1999; Mei et al. 2001; McDade et al. 2004).

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